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WITH ABSTRACT OF THE LITERATURE

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Modern Problems in Industrial Medicine

Recent Research into the Causes of Industrial Accidents

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The Measurement of Radiant Heat in Relation to Human Comfort

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THE JOURNAL OF INDUSTRIAL HYGIENE

VOLUME XIV MARCH, 1932 NUMBER 3

MODERN PROBLEMS IN INDUSTRIAL MEDICINE*

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THE present is an important time for planning for the future. Industrial medicine, after passing through many phases, is now entering a new era which is directly associated with the economic difficulties of the time. Mechanization; the increased competition of girls with men; the tendency to speed up industrial processes; the effect of mass production and the elimination of the small concern, combined with the growing realization that interdependence and co-operation are vital factors; all present new problems for the industrial doctor which are in addition to his already accepted sphere in the study of specific industrial hazards.

The great majority of persons engaged in industry and commerce do not so much need protection from their work as they need adjustment to the industrial civilization of which they form an integral part. Our task is to make of the industrial population a source of strength and not a source of weakness, and we have to insure that as a result of modern industrial and commercial procedure and environment we do not saddle ourselves with a large number of disintegrated and therefore unhappy, discontented and unhealthy men and women.

In the absence of international agreements, mechanization almost certainly means fewer man hours of work, either as unemployment or as increased leisure. We are also confronted with medical problems associated with increased speed of production.

The need of industry appears to be for the higher intellectual type; it is, therefore, highly significant that this is the type which at present appears to be the most prone to incapacitating illness, often of a psychoneurotic character. It is obvious that real

*Abstract of an address to the Medical Advisory Committee of the Industrial Welfare Society on Oct. 23, 1931.

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education in the art of living will be needed before we shall begin to see any great reduction in the amount of incapacity.

Medical work organized among groups of small firms is even more important than medical work in large concerns.

The educational activities in industry are of great importance, especially Day Continuation Schools, but they operate only with young persons over 14 years of age. The time to start educating a child to adapt himself to our present complex and shifting systems is at the very earliest stage of the educational process; we badly need the help and advice of practising medical psychologists who from their clinical experience will be able to advise on the best methods of overcoming the very pronounced tendency of the industrial worker to disintegrate, not so much in respect to his work as in relation to his whole mechanized environment. This is a vast problem.

The tasks before industrial medicine at the moment are: (1) co-operation with educationists in order to produce a healthy and adaptive sense of values; (2) the determination on the part of doctors to study psychologic problems and especially the minor psychoneuroses; and (3) a more sympathetic understanding of the problems of management on the part of medical men.

The economic war is essentially conflict between unsatisfied mass minds. If we wish to produce and to maintain a healthy industrial population it is of the most urgent necessity that we shall be able to supply some form of really satisfying goal or ideal for the industrial community. The present supply of satisfaction is quite inadequate—football, greyhounds, films, and other passive amusements cannot supply what is needed; we who have such unique opportunities for first-hand study of the industrial worker should impress on those in authority the serious problems involved. This is a national task and cannot be relegated to industrial concerns since it is economically impossible.

Two cardinal facts emerge:

1. Unless something is done, our industrial system will suffer increasingly both from lack of mental initiative and from increased incapacity associated with a general shiftlessness and irresponsibility engendered by unwise social services.

2. Defensive mechanisms against the physical and mental effects of the economic barrage are as vital to our economic existence as is the problem of military defense to our territorial security.

It is not increased expenditure which is needed but an enlightened use of that which is already sanctioned.

Political considerations separate the educational policies of the main parties in many respects; and statesmen do not yet seem to realize how far they are really responsible for the inculcation of methods of thought (as opposed to passive instruction), by which alone we can recruit into industry the human material which we, for our part, wish to see fit and well and happy.

Arising out of this there is urgent need that social students and welfare workers should study these problems and be far more alive to the practical aspects of industrial medicine than they are at present; and, further, directors of education throughout the

country should be asked to co-operate in the important work of widening the mental basis of the child, on which subsequently he or she can build an adequate defensive mechanism against the complex and shifting demands of modern life.

Industrial medicine at present is largely preventive; but the preventive measures are mostly on the physical plane. The more vital mental problems can be dealt with only on broad lines; the preventive field for these lies outside industry; but in the framing of policy no opinion can be of greater value than that of the industrial doctor who sees, as no family doctor can see, the actual vital combination of man at work. Whatever is human is medical; therefore, to my mind, in industrial medicine wisely guided lies in no small measure the responsibility for this strange, complex and unstable system which we call modern civilization.

RECENT RESEARCH INTO THE CAUSES OF INDUSTRIAL ACCIDENTS*

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I. EXTERNAL FACTORS AFFECTING ACCIDENT CAUSATION

THE object of these lectures is to present the results of recent research on industrial accidents in a nontechnical form so that they may be easily available to those who are interested in the prevention of accidents.

Home Office regulations dealing with guards to machinery and with the avoidance of dangerous practices have done much to lessen the number of industrial accidents, but however good such regulations are and however well they are observed, they have their definite limitations. The safety movement, by the formation of works safety committees, and by propaganda, has done much to prevent accidents that could not be prevented by regulations alone. The movement has fostered a widespread interest in accident prevention which has had the effect of making people realize how important it is to lessen the number of industrial accidents, which, besides causing much suffering, also entail great economic loss to the country. Before serious efforts can be made to prevent accidents, there must be a widespread interest which will welcome any wise proposals that are made to lessen one of the great evils of modern industrialism. The contributions of the scientist to accident prevention lie outside the sphere of regulations or propaganda and consist in trying to surmount some of the many interacting causes that determine accident rate.

Fatigue is one of these causes, for a tired worker is specially liable to accidents. It is, however, difficult to separate the part played in accidents by fatigue from the part played by speed of production, which is possibly a more important factor under modern industrial conditions. Much can be done to mitigate the bad effects of speed by arranging the work so that it fits the natural rhythm of the worker instead of running counter to it. Sometimes by lessening the speed of a machine the total output is increased and the worker's liability to accidents reduced because he is working more within his capacity, and therefore works regularly instead of in rapid spurts alternated by rests.

Bad atmospheric and lighting conditions also have the effect of increasing liability to accidents. The study of ventilation and illumination has so greatly advanced in recent years that there is little excuse in most industries

*Synopsis of three lectures given under the Heath Clark bequest on Nov. 2, 9, and 16, 1931. The publication of these lectures in book form is under consideration.

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for the continuation of conditions which are known to contribute toward a high accident rate.

There is little difference between the accident rates of day and night shifts although the period of the work spell at which the accident rate is highest is different—a fact which suggests that the causes of accidents are different in the two periods of work. There is a tendency for accidents to be higher immediately before and after the week-end; this may to some extent be due to the excitement caused by anticipating and recollecting the period of rest.

Accidents are more numerous among the young, and more serious among the old. The greater number of severe accidents sustained by older persons is not due to the fact that their accidents are originally more serious but to the fact that they are less able to resist the results of any accident they sustain, and so are off work for a longer period. Want of experience is also a causal factor in accidents but not such a powerful one as youthfulness, with which it is so often associated.

Those workers who have most accidents also tend to have more sicknesses than others. It is possible that certain persons find the strain of modern industry too great and consequently react unfavorably to it.

II. Personal Factors Affecting Accident Causation

It has always been known that some persons have more accidents than others. This has been regarded by some as a matter of chance, as the word accident itself implies. Others have thought that having an accident predisposed one to have others. The adage that if we break something we are sure to break two other things within a short time implies this belief. A third suggestion is that some persons are inherently more liable to accidents than others. Recent statistical researches have made it clear that the last of these three explanations is in closest agreement with the facts. This is an important result, for it opens up a new field for research in accident causation. If some persons are more liable to sustain accidents than others exposed to the same risk, we can then go on to inquire in what other ways these persons differ from their fellows. Any light that can be thrown on this question will be a definite step forward in the study of accident causation.

These statistical investigations also showed that those who tended to have an undue number of trivial accidents also tended to have an undue number of serious accidents, and that this tendency to have accidents was a stable peculiarity of the individuals who had it, predisposing them to have a similar number of accidents in one period as in another of equal length when exposed to the same risks.

Another result of these investigations was the construction of a table by means of which it is possible to determine whether the accident rate of a department is mainly due to factors affecting all members equally or to the fact that it contains certain accident-prone individuals. Although this table was constructed by means of intricate statistical methods, its use is very simple and requires no more arithmetic than is involved in finding the average accident rate of the department. The practical value of such a table in accident prevention is considerable, for by means of it one knows whether general working conditions

should be altered or certain individuals specially studied, in order to reduce the accidents of a department.

As a result of a psychologic investigation it has been found that those who failed in certain sensorimotor tests had an accident rate two and a half times greater than those who passed. These tests were given before the subjects entered their employment, and the subsequent high accident rate of those failing in the tests shows that it is to some extent possible by means of psychologic tests to determine beforehand those who are especially liable to accidents and so warn them against entering a dangerous trade. Research is still continuing to see whether it is possible to measure other psychologic qualities that may be involved in accident proneness.

There is some evidence to show that those who are specially prone to accidents are also less proficient at their trade, but it is not sufficient at present definitely to warrant this conclusion.

III. Practical Application of Knowledge Concerning Causes of Accidents

It is essential that accident records should be kept in such a way that they can be easily analyzed. If they are kept in a book, as is too often the case, the difficulty of analyzing them is so great that it is never properly done. The card index system is a much simpler means of recording accidents at the time they occur and makes the proper analysis of the accidents of any group of workers from time to time a very simple matter. Full details as to age, length of employment, and occupation should be entered when the card is made out. The time, place, and nature of the accident should be recorded, and it should also be stated what the worker was doing at the time the accident occurred and, if possible, what caused it.

With this information at our disposal the accident records of any factory can be examined once a year to see the extent to which various causes are influencing the accident rate. By using the table referred to in the second lecture, it can be decided whether accidents are mainly due to factors affecting all alike or to the presence of specially accident-prone persons. If a department is found to contain such individuals—there are never more than a few in any group of workers—then it may be possible to transfer them to some less dangerous occupation or to make special arrangements for their protection.

If it is found that the accidents in a department are mainly due to conditions affecting all alike, then general working conditions such as lighting, ventilation, and layout can be examined to see whether they can be improved.

Sicknesses should be recorded on the same card as accidents, together with the lost time due to these and other causes. If certain individuals are found to be ill more often than others and also to have an undue number of accidents, it may be advisable to have them medically examined. Such an examination may suggest remedial treatment that will result in a general improvement in health and a consequent diminution of accidents.

If accident records are kept in such a way that they can be easily analyzed, they will not be mere records but will be a basis for determining the causes of accidents, which is the first step toward preventing them.

J. I. H.
March, 1932

FACTORS IN THE PRODUCTION OF NERVOUS LESIONS FOLLOWING ELECTRIC SHOCKS*

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INTRODUCTION

IN connection with previous morphologic studies of the damage produced in the central nervous system by electricity (1) (2) (3), two questions, in particular, were suggested for further study.

The first of these was concerned with the course of the current through the body and the relation of different pathways to the severity of nervous lesions. It is difficult to believe that a current passing from arm to leg would produce marked damage to the brain. Assuming the specific resistance of the body as uniform, the current in its passage extends out in a fusiform shape but it is not to be expected that the current density in parts remote from the main pathway is high. The physiologic results of variations in the current pathway have already been described (4); the present paper deals with the histologic findings.

The second question has to do with heating as a factor in the production of lesions of the nervous system following electric injuries. It is known that the brain becomes very warm when one electrode is placed upon the head and a current is allowed to pass through the body. In the experimental work, using direct and alternating circuits at 500 and 1,000 volts, severe burns were produced, sufficient to cause coagulation of muscle and necrosis of bone. It seemed important to control the studies of nerve cell damage caused by electric currents by determining the importance of heat in the production of the lesions. An opportunity to work with the impulse or lightning generator made this possible (5).

The impulse or lightning generator has recently assumed great importance in the electrical industry owing to its value in testing high voltage insulation, inasmuch as the discharge is similar to a lightning stroke. The principle of the generator is like that of a Leyden jar. The jars may be charged in parallel and discharged in series. This provides a high voltage circuit discharging for only an extremely small fraction of a second. In the circuit used in the experiments the entire duration of the discharge did not exceed four and one-half millionths of a second. The crest value reached by the current during this short period was of the order of 100 amperes, and the maximum potential 200,000 volts. The spark jumped from a wire suspended from the machine about a foot or more, to a grounded copper plate. The period of contact was so brief and the amount of energy so small that

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there was little rise in body temperature and the heat produced was negligible. Again, the physiologic findings have been reported and the results of study of sections of the nervous system are now to be considered.

Morrison, Weeks, and Cobb (6) studied the temperature of the brain at the time when electric currents were flowing through it. Three holes were made in the skull of a cat under anesthesia. One hole was just to one side of the midline and the others well out on the left and right lateral surfaces of the skull. Into each of the lateral holes a copper electrode was inserted which reached down into the brain but not into the ventricles. In the middle hole was introduced a thermojunction. Little or no heating was produced as long as the blood circulated through the brain, even when an electric circuit of 400 volts was used. Upon cessation of the cerebral circulation the temperature of the brain rose at once.

The experiments described here were all performed upon rats. This animal was in some ways ideal, inasmuch as the heart recovers spontaneously from fibrillation and is seldom seriously affected by the current. Only after shocks from the impulse generator could cardiac damage be demonstrated. The animals discussed in the present experiments either died as an immediate result of the injury or were killed within twenty-four hours. Immediately after death the brains were removed and fixed in 95 per cent. alcohol. Sections were cut and stained with thionin to demonstrate nerve cell damage.

Experimental Findings

Effect of Varying Pathway of Current through Body

One hundred and two new experiments and eleven from previous work comprise this series in which rats were subjected to either a direct or an alternating circuit at 1,000 volts for one second. They will be discussed in four groups. The contact between head and tail has been used in many of the author's experiments since it insures the passage of the current throughout the entire length of the nervous system. The results of such a shock and the histologic findings will constitute the first group. The second will include the cases in which the current passed between electrodes attached to either foreleg and either hind leg or to either foreleg and tail. Contacts across the chest through electrodes upon the two forelegs will constitute the third group. Finally the contacts between the two hind legs will be considered.

Electrodes Applied to Head and Tail

Alternating Circuit.—These observations serve to control the present series and correlate it with previous observations by the author (1). There were sixteen rats; artificial respiration was required in the case of 88 per cent., whereas the remainder breathed normally following the injury. Thirty-one per cent. of the rats appeared normal after the shock; 38 per cent. showed a paralysis of the hind legs, and 31 per cent. died at once.

The findings were similar to those of the previous series (1). Hemorrhages in the central nervous system

were very frequent. All the paralyzed animals showed a hemorrhage in the spinal cord, involving the region of the posterior columns and extending longitudinally a considerable distance in the upper thoracic and cervical regions. In a few instances it broke into the central canal. Hemorrhages in the ventrolateral columns of the cord occurred but were infrequent. In two of the rats which died immediately following the shock, large accumulations of blood were present in the fourth ventricles. Other evidences of hemorrhage were found in the subarachnoid space. Morrison, Weeks, and Cobb have emphasized the frequency of hemorrhages following contact with alternating circuits. It was suggested that the hemorrhages occurring in the posterior columns were produced by the sudden violent flexion of the body at the moment when the circuit was closed. In view of the frequency of bleeding in the brain it is perhaps more probable that all the hemorrhages are due to the sharp rise in blood pressure which follows the shock.

There were also demonstrable changes in the nerve cells throughout the central nervous system. These were more marked in the animals that lived a few hours following the injury than in those which died at once. The granules of the nerve cells were greatly decreased in a number, and vacuoles appeared in the cytoplasm. Occasionally extrusion of the cell nucleus was seen. Many of the cells were shrunken and stained deeply; these were surrounded by a large perivascular space. Perhaps the Purkinje cells of the cerebellum showed the most marked injury.

It has already been emphasized that all the cells of a group do not show an equal amount of injury. For example, in the dorsal nucleus of the vagus a certain number of cells showed marked shrinkage, whereas the others appeared relatively normal.

The most marked and instructive changes are observed in the cell nucleus. A swelling of the nucleolus often occurs in cells that are slightly damaged. With more marked abnormality the whole nucleus is shrunken, and stains deeply so that it shows no differentiation of characteristic structure and the nucleolus cannot be observed. It was suggested in a previous paper that a cell with this severely damaged nucleus had no chance of recovery. If sufficient cells were damaged to this extent it is probable that the animal would not survive even if adequate artificial respiration were continued for an indefinite time.

Continuous Circuit.—There were only three animals in this group which serves to control a previous series already described. A contact through electrodes on the head and tail with a 1,000-volt continuous circuit for one second was always fatal to rats even though artificial respiration was given.

The continuous current produced more severe changes in the nervous system than did the alternating. Small cavities were often present in the gray matter near the surface of the cerebral cortex and also in the brain stem and cord. These cavities are thought to be due to heating or to electrolysis. Hemorrhages were relatively infrequent.

The nerve cell damage was of similar

type to that described for the alternating circuits but it was more severe. Moreover, there was much more evidence of destruction of injured nerve cells by phagocytes than in the alternating circuit series. There were also fewer shrunken cells, a greater loss of granules, and more damage of the cell nucleus. The injury was again selective, choosing certain cells of a group, but it extended throughout the entire length of the nervous system. This severe injury of the nerve cells is responsible for the immediate death of all the animals.

Electrodes Applied to Either Foreleg and Either Hind Leg or Tail

Alternating Circuit.—These experiments with thirty-six animals are grouped together inasmuch as the direct pathway of the current did not traverse the head but ran in a direction parallel to the spinal cord. Therefore, comparing the damage in the brain and cord, it is possible to obtain information concerning the amount of destruction that occurs in nervous tissue outside the main pathway of the current.

When the immediate physiologic results of the shock were summarized it was found that 42 per cent. of the rats died as a result of the injury, 17 per cent. were paralyzed, and 41 per cent. were apparently normal. There were more complete recoveries and more deaths than in the alternating series with the electrodes attached to head and tail; the number of paralyzed animals was, on the other hand, decreased from 38 to 17 per cent. The decrease of paralysis may be attributed to less direct involvement of vasomotor mechanisms in the medulla. The current density in the chest of this small animal was high owing to the position of the electrode upon the proximal portion of one of the forelegs. A 1,000-volt alternating current produces considerable heating near the electrodes. Moreover, a temporary block of the vagus nerves inhibited respiration. It is clear that the heart was not severely injured since it beat well following the shock.

The histologic study was illuminating, in that there was very little evidence of nerve cell damage in the medulla, while the cord showed changes similar to those already described. There were, however, hemorrhages in the region of the brain and there were large hemorrhages filling the fourth ventricle in five of the rats which died immediately following the shock. The hemorrhages, therefore, are dependent upon changes in blood pressure, whereas the nerve cell damage is marked only in areas traversed by the current.

Continuous Circuit.—Similarly thirty-six rats were shocked from the continuous circuit. There were twenty-four in which the current passed from either foreleg to the tail; of these, 42 per cent. recovered at once, 38 per cent. were paralyzed, and 25 per cent. died immediately following the injury. On the other hand all of the twelve rats which were subjected to a current passing from either foreleg to either hind leg died at once. Considering these results together, it is clear that there was a greater recovery than in the cases previously described in which one electrode was placed upon the head. A great amount of heat was developed near the site of the electrodes, and this was followed

by extensive necrosis, so that none of the rats shocked in this way had a chance of permanent survival. It was probably this heat that was responsible for the deaths. In the group with deaths of all the animals the current pathway crossed from one foreleg to the opposite hind leg, thus traversing the chest. In all these animals the heart beat well following the injury. The vagus nerves must have been profoundly injured by the current, with resulting nerve block and respiratory paralysis.

Marked changes were found in the spinal cord. There were many small cavities which are thought to be produced by heat. Moreover, the nerve cells showed marked changes manifested as loss of granules, extrusion of the nucleus, and abnormal staining of the nucleus. The cavities were not present in the region of the medulla nor were nerve cell changes found there. It was demonstrated, therefore, that nerve cell damage was not marked far from the main pathway of the current.

Electrodes Applied to Forelegs

Alternating and Continuous Circuits.—Four animals were subjected to the alternating and four to the continuous current with the electrodes attached to the forelegs. All of these rats died immediately following the shock. With the two electrodes so close together in this small animal a great amount of heat was produced in the chest; this was much more marked with the continuous than with the alternating current. Moreover, considerable current must have passed through the vagus nerves and a block in nerve conduction must have occurred. No heart beat could be detected in one rat after continuous current injury; the heating coagulated the musculature of the chest wall and may have coagulated the heart musculature. Again examination revealed marked changes in the cells of the thoracic portion of the spinal cord but no injury of the cells in the region of the medulla.

Electrodes Applied to Hind Legs

Alternating and Continuous Circuits.—This group of fourteen experiments, seven with the continuous and seven with the alternating circuit is interesting inasmuch as the main pathway of the current traversed the central nervous system very little if at all. Nevertheless, 14 per cent. of the alternating series and 29 per cent. of the continuous died immediately following the shock. All of the continuous group were so severely burned that recovery was impossible. The pathway of the current certainly did not traverse the respiratory mechanism directly. However, the strong stimulation from lumbar and sacral nerves might produce inhibition of cerebral centers lasting for a considerable period. The animals that survived were much more active immediately following the shock than were the other groups already described. Very little damage to the nervous system either in the way of damage in nerve cells or hemorrhage could be demonstrated in these cases.

Histologic Changes Produced in Nervous System by Shocks from Impulse Generator

It has already been explained that little heat was produced by the rapid discharge of the impulse generator;

the body of the rats never felt warmer than normal after the shock. The histologic changes will be discussed in this paper only inasmuch as they demonstrate that an electric current produces marked changes in the nervous system even when heating does not occur. Later, with a larger series of cases it is hoped that the rather remarkable abnormalities may be discussed further.

The rats were oriented in reference to the spark gap in various ways so that the current flowed through the whole length of the body or through isolated portions. In some the current passed through the head; in other cases the head was outside the main pathway of the current. This produced differences in the histologic picture in the nervous system similar to those in the groups just discussed.

The blocks of brain and cord were fixed as usual in 95 per cent. alcohol. It was after fixation that the first changes were noticed; it was found that the blocks became very granular and crumbly, showing a great tendency to disintegrate during the process of paraffin imbedding. This change was marked in the case of the nervous systems of the rats which died immediately, but occurred to a less extent in those which survived. This damage was of course seen clearly in the finished sections, many of which were broken into small bits. It was felt that this was a result of the injury and not an error in technic, because it was much more severe in the animals that died at once following the shock and also because it was most marked in the portions of the nervous system directly traversed by the current. The brain in many cases was broken into small fragments, as if there had been a great explosion of the brain substance. When one considers the blow striking these structures, 100 amperes acting for only a small fraction of a second, it does not seem strange that such a breaking down of tissue should have occurred. It seems probable, however, that it is dependent upon some chemical change in the tissues as a whole.

Turning now to the nerve cell damage, this was more evident in the rats that survived the shock although it could be demonstrated in those dying immediately. In the latter case many of the cells showed a loss of granules and dark shrunken nuclei. The nuclei in some cases were displaced to the edge of the cell. The Purkinje cells of the cerebellum perhaps showed the most marked changes. In some cells granules were grouped at one edge, whereas the remainder of the cytoplasm was free from them.

Shrinking of nerve cells was the most marked change in the central nervous systems of rats which survived the injury for several hours. This was noticed everywhere and particularly in the Purkinje cells of the cerebellum. Vacuoles occurred in the cytoplasm of other cells, and apparent rupture of the cell membrane was observed frequently. The impulse generator, therefore, produced marked damage to the nervous system demonstrable by histologic examination.

Discussion

If the experimental findings are now evaluated it seems clear that shocks from 1,000-volt alternating or continuous circuits for one second produce demonstrable damage of the nerve

cells only in portions of the nervous system directly traversed by the current. However, with a higher voltage circuit or with a contact for a longer period of time, generalized heating of the body introduces another factor producing damage. Unfortunately histologic changes in nerve cells are not specific for different physical traumas. It is well known that in cases of legal electrocution the brain becomes very warm. The author reported an autopsy following an electrocution from a circuit of 2,200 volts (2); the contact probably lasted several minutes so that the body was badly burned. In this case there were marked changes in the cells of the medulla even though the pathway of the current was from arm to leg. It must be considered therefore that if the body heat is elevated by an electric current to a considerable height, changes in the delicate nerve cells may be expected everywhere. Morrison, Weeks, and Cobb showed that there was no rise in brain temperature as long as the cerebral circulation was competent. If a discharge from a circuit of over 500 volts passes through the body, the heart musculature remains in tetanic contraction during the period of the shock. Under these conditions the body temperature must rise very rapidly.

Particularly after contact with a continuous circuit, cavities may be demonstrated in the brain and spinal cord. Since they are found only after contact with a circuit of rather high voltage, it is probable that they are produced by heating.

There is another cause, in addition to heat, for abnormalities in nerve cells outside the main pathway of the current. The current passing through the peripheral nerve trunks must give rise to very strong impulses which are carried to the nervous system. These excessive impulses produce changes in the cell similar to those which have been described as typical of nerve cell fatigue. Thus with the current passing through the chest, the vagus nerves would be stimulated, producing demonstrable changes in the nuclei in the medulla. It has been shown quite clearly that a block can be produced in peripheral nerves by a current which does not traverse the central nervous system.

When the current flowed from one hind leg to the other, the nervous system did not lie directly in the pathway; yet several rats failed to breathe and died immediately following the shock. In these cases it is probable that impulses carried to the nervous system through the sensory nerves produced a severe shock which interfered with the resumption of respiration.

Summary

When the current from a 1,000-volt alternating or continuous circuit was allowed to flow through the preparation for one second, abnormalities in the nerve cells of the brain or the spinal cord were demonstrated only in areas traversed directly by the current pathway. The electric current produced damage to nerve cells in experiments where heat production was negligible. If a large current flows through the body for a considerable time, there is marked heat production which causes changes in nerve cells indistinguishable from those produced by the electric current alone.

the body of the rats never felt warmer than normal after the shock. The histologic changes will be discussed in this paper only inasmuch as they demonstrate that an electric current produces marked changes in the nervous system even when heating does not occur. Later, with a larger series of cases it is hoped that the rather remarkable abnormalities may be discussed further.

The rats were oriented in reference to the spark gap in various ways so that the current flowed through the whole length of the body or through isolated portions. In some the current passed through the head; in other cases the head was outside the main pathway of the current. This produced differences in the histologic picture in the nervous system similar to those in the groups just discussed.

The blocks of brain and cord were fixed as usual in 95 per cent. alcohol. It was after fixation that the first changes were noticed; it was found that the blocks became very granular and crumbly, showing a great tendency to disintegrate during the process of paraffin imbedding. This change was marked in the case of the nervous systems of the rats which died immediately, but occurred to a less extent in those which survived. This damage was of course seen clearly in the finished sections, many of which were broken into small bits. It was felt that this was a result of the injury and not an error in technic, because it was much more severe in the animals that died at once following the shock and also because it was most marked in the portions of the nervous system directly traversed by the current. The brain in many cases was broken into small fragments, as if there had been a great explosion of the brain substance. When one considers the blow striking these structures, 100 amperes acting for only a small fraction of a second, it does not seem strange that such a breaking down of tissue should have occurred. It seems probable, however, that it is dependent upon some chemical change in the tissues as a whole.

Turning now to the nerve cell damage, this was more evident in the rats that survived the shock although it could be demonstrated in those dying immediately. In the latter case many of the cells showed a loss of granules and dark shrunken nuclei. The nuclei in some cases were displaced to the edge of the cell. The Purkinje cells of the cerebellum perhaps showed the most marked changes. In some cells granules were grouped at one edge, whereas the remainder of the cytoplasm was free from them.

Shrinking of nerve cells was the most marked change in the central nervous systems of rats which survived the injury for several hours. This was noticed everywhere and particularly in the Purkinje cells of the cerebellum. Vacuoles occurred in the cytoplasm of other cells, and apparent rupture of the cell membrane was observed frequently. The impulse generator, therefore, produced marked damage to the nervous system demonstrable by histologic examination.

Discussion

If the experimental findings are now evaluated it seems clear that shocks from 1,000-volt alternating or continuous circuits for one second produce demonstrable damage of the nerve

cells only in portions of the nervous system directly traversed by the current. However, with a higher voltage circuit or with a contact for a longer period of time, generalized heating of the body introduces another factor producing damage. Unfortunately histologic changes in nerve cells are not specific for different physical traumas. It is well known that in cases of legal electrocution the brain becomes very warm. The author reported an autopsy following an electrocution from a circuit of 2,200 volts (2); the contact probably lasted several minutes so that the body was badly burned. In this case there were marked changes in the cells of the medulla even though the pathway of the current was from arm to leg. It must be considered therefore that if the body heat is elevated by an electric current to a considerable height, changes in the delicate nerve cells may be expected everywhere. Morrison, Weeks, and Cobb showed that there was no rise in brain temperature as long as the cerebral circulation was competent. If a discharge from a circuit of over 500 volts passes through the body, the heart musculature remains in tetanic contraction during the period of the shock. Under these conditions the body temperature must rise very rapidly.

Particularly after contact with a continuous circuit, cavities may be demonstrated in the brain and spinal cord. Since they are found only after contact with a circuit of rather high voltage, it is probable that they are produced by heating.

There is another cause, in addition to heat, for abnormalities in nerve cells outside the main pathway of the current. The current passing through the peripheral nerve trunks must give rise to very strong impulses which are carried to the nervous system. These excessive impulses produce changes in the cell similar to those which have been described as typical of nerve cell fatigue. Thus with the current passing through the chest, the vagus nerves would be stimulated, producing demonstrable changes in the nuclei in the medulla. It has been shown quite clearly that a block can be produced in peripheral nerves by a current which does not traverse the central nervous system.

When the current flowed from one hind leg to the other, the nervous system did not lie directly in the pathway; yet several rats failed to breathe and died immediately following the shock. In these cases it is probable that impulses carried to the nervous system through the sensory nerves produced a severe shock which interfered with the resumption of respiration.

Summary

When the current from a 1,000-volt alternating or continuous circuit was allowed to flow through the preparation for one second, abnormalities in the nerve cells of the brain or the spinal cord were demonstrated only in areas traversed directly by the current pathway. The electric current produced damage to nerve cells in experiments where heat production was negligible. If a large current flows through the body for a considerable time, there is marked heat production which causes changes in nerve cells indistinguishable from those produced by the electric current alone.

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THE MEASUREMENT OF RADIANT HEAT IN RELATION TO HUMAN COMFORT*

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INTRODUCTION

ACCURATE estimation of the parts played by radiation and convection in various heating systems, when considered in relation to their influence on bodily warmth, is a difficult problem, for the radiation which impinges on the body is never derived from a single direction, as from the fire or other heating source in the room. The radiation from the fire warms the walls and other objects in the room to varying degrees, according to their proximity, and they in turn radiate heat. In fact, as was pointed out by Prevost more than a century ago, all bodies are continuously radiating heat to one another, those at a constant temperature receiving just as much heat as they lose. For most practical purposes it is convenient to ignore the exchange of radiation by bodies of equal temperature, and to consider only the gain or loss of radiant heat by bodies of different temperatures.

A person sitting in a room heated by a fire, in addition to receiving positive radiation from the fire and from objects warmed by it, is also subject, as a rule, to what may be termed *negative* radiation from the windows, as they are generally colder than the air of the room. These varying degrees of positive and negative radiation cause a summated heating effect on the person's body, or more strictly speaking, they retard the cooling of his warm body to an extent dependent on their magnitude. The clothed human body has an average surface temperature of about 75°F. (1), and therefore it is usually radiating considerably more heat than it receives. What we want to ascertain is the mean positive (or negative) radiation falling on the whole surface of the body, and the extent to which it would heat that surface above the temperature of the surrounding air, supposing the body itself were not producing heat internally.

The radiation from any given source can be accurately estimated by means of a bolometer or radiometer, and it would be possible by directing the instrument in turn to every angle and quarter of the room, to measure the radiation received from all directions. Even then, however, we should not obtain a correct measure of the radiation as it affected the human body. In order to give a simple explanation of what happens, it is best for the moment to regard the body as a clothed lay figure producing no internal heat. When heat rays strike the surface of such a figure they warm it to a temperature above that of the surrounding air, and the warmed sur-

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face at once begins to lose heat to the air. The rapidity with which this occurs depends on the velocity of the air currents moving against it as well as on other factors, and it cannot be at all accurately predicted from a knowledge of the intensity of the radiation received. For instance, we shall see that if the radiation from a stove warms up a cloth surface 5°F. in calm air, a moderate air current (270 feet per minute) will reduce the extent of the warming to a third the figure quoted. Hence the *effectual radiation* received by the clothed lay figure, under a given set of conditions, is indicated by the average excess temperature of the whole of its surface above that of the surrounding air. It is true that the air has itself been warmed by a transference of heat from the surface radiated upon, and in consequence of this warming it helps to maintain the lay figure at a higher temperature than before. This warming effect, however, is due really to convection air heating and only indirectly to radiation. What happens to the lay figure happens also to the warm human body, except that the effectual radiation, instead of warming the body still further, merely retards the normal heat loss in proportion to its intensity.

In order to estimate the *effectual radiation temperature* to which a human body is subjected when exposed to radiation from the various heating and cooling sources in a room or elsewhere, it is therefore necessary to devise some convenient portable instrument which will record in a single measure the summated effect of the diverse radiations from all sources, negative as well as positive. The instrument which is found to fulfil these requirements has been named the *globe thermometer* (2).

An instrument named the eupatheoscope has been designed by Dufton (1) for measuring summated convection and radiation effects in the laboratory. It consists of a black-painted, hollow copper cylinder 22 inches high, which is heated electrically so as to maintain a surface temperature of 75°F. The power supplied, which is controlled by a thermostat, is recorded, and the heat loss from the cylinder when the temperature of the air and walls of the room are at 64.3° is regarded as the normal standard of thermal comfort for human beings. At lower air temperatures the power required to maintain the surface temperature of the cylinder is increased, but if radiant heat is impinging on it, the requisite power is diminished in proportion to the radiation received. Observations have been made with this apparatus in a schoolroom (3), as well as in the laboratory.

An instrument for measuring the cooling power of the environment, termed the coolometer, has been designed by Weeks (4). It is made of copper, and is 3 inches in length. Its surface is electrically heated to a constant temperature, the current required being a measure of the rate of cooling.

The Globe Thermometer

When a thermometer is exposed to direct radiation from such a source as a gas fire, it indicates a higher temperature than a protected thermometer; and if its bulb is covered with cloth, it indicates a higher temperature still. The larger the bulb

the greater the excess of temperature indicated, but as very large bulbs are impracticable, the simpler plan was adopted of using a hollow spherical bulb or globe with a thermometer of ordinary size at its center. For instance, the ordinary black bulb solar radiation thermometer is enclosed in a glass sphere $2\frac{1}{2}$ inches in diameter (Fig. 1), and if the surface of the glass is coated with mat black paint so as to prevent the direct penetration of heat rays to the black bulb within, the equivalent of a $2\frac{1}{2}$-inch bulb thermometer is obtained. We shall see, however, that even this size is much too small, and that a globe 6 or 9 inches in diameter is necessary in order to obtain a radiation effect comparable to that experienced by the human body.

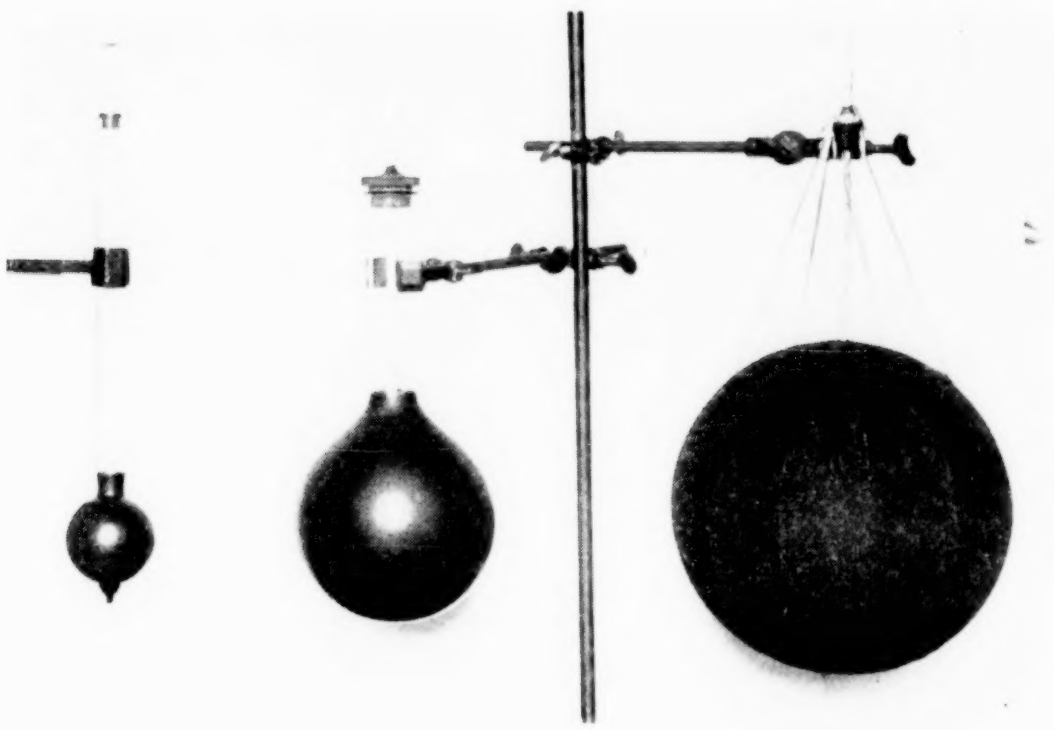

FIG. 1.—Showing a 9-inch cloth covered globe thermometer, a 6-inch black-painted glass flask thermometer, and a $2\frac{1}{2}$-inch black-painted solar radiation thermometer.

Most of the globe thermometers used consisted of pasteboard covered with cloth. The globe was freely suspended as is seen in Figure 1, in which a 9-inch globe covered with dark gray cloth (such as is used for men's clothes) is shown. The thermometer was fixed with its bulb in the center of the globe. Another form of globe thermometer consisted of a spherical 6-inch glass flask, which was coated inside and outside with mat black paint. The passage of heat rays down the neck of the flask to the bulb of the contained thermometer was prevented by a cork diaphragm. This glass globe thermometer has the great practical advantage over the cloth globes of a comparatively small time lag. When the globes were transferred from a room at a temperature of 50° to one at 70°, the glass globe thermometer reached the air temperature in twenty-five minutes, while 6-inch and 9-inch cloth covered globes took 115 minutes. The most convenient globe thermometer of all was of thin copper, and was likewise 6 inches in diameter. Such globes can be obtained commercially as they are used for ball cocks, and it is only necessary to solder on a short tubulure in which to insert a cork piereed by

the thermometer. The globe was painted mat black, and it showed a very slightly higher temperature than the 9-inch cloth globe. It had a rather shorter time lag than the glass globe; in moving air (at a velocity of 270 feet per minute) the lag was less than fifteen minutes, as can be seen from Figure 2.

Radiation from Gas Fire

In order to obtain comparable data, systematic readings of the thermometers were made when the globes were exposed to the radiation from a gas fire 13 by 9 inches in area. The globes were 3 feet above the floor and 4 to 5 inches apart; usually three globes and one or two control thermometers were tested at a time. The bulbs of the contained thermometers were fixed 6 feet from the center of the fire and were, therefore, arranged in the arc of a circle; even then, however, the outer instruments received less radiation than the center ones, in accordance with the well-known cosine law of illumination, which applies equally to radiant heat. In order to counteract this source of error, the position of the instruments in relation to one another was changed after their temperature had been read, and a second reading was taken later on. Observations were made in nearly still air, when the average velocity was found (by kata-thermometer) to be 12 feet per minute. They were also made in moving air, induced by the revolutions of a 12-inch electric fan which produced an average air velocity of 270 feet per minute. The thermometers were left in position long enough to avoid the error due to lag.

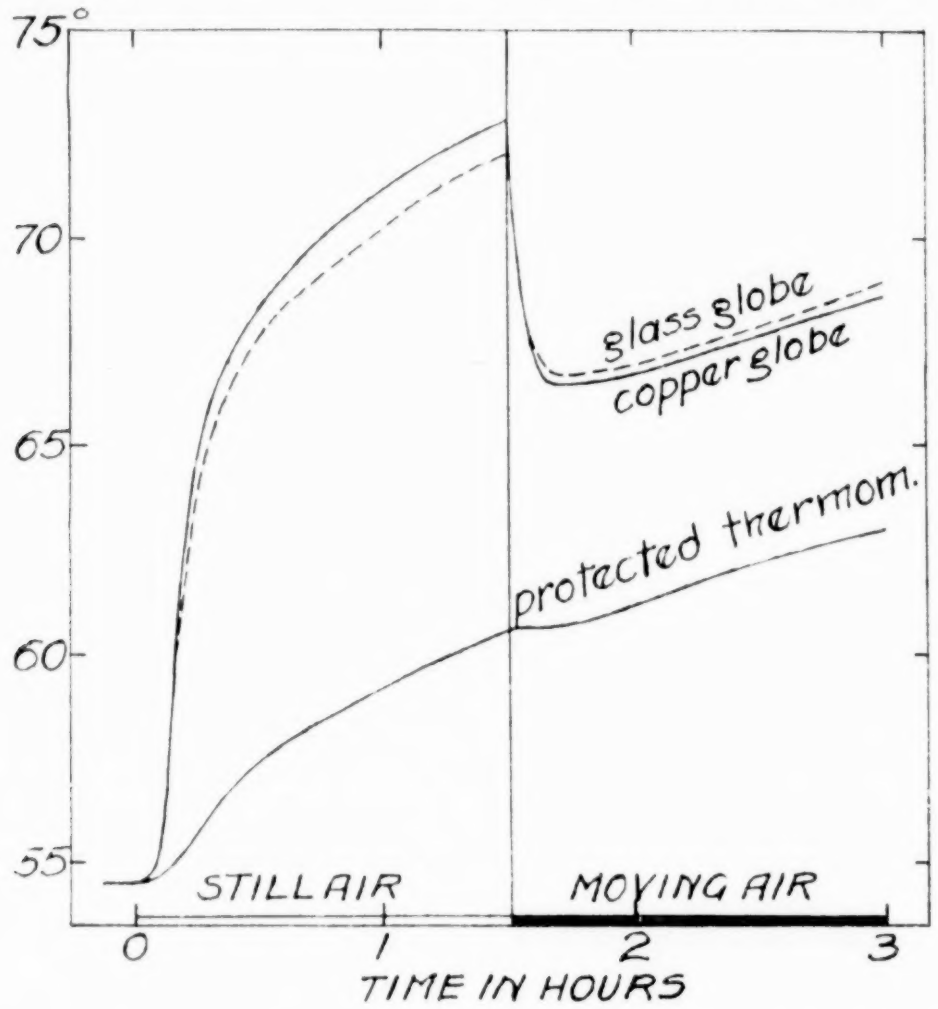

FIG. 2.—Temperatures shown by thermometers fixed 6 feet from gas fire.

In order to ascertain the correct air

temperature, the small-bulbed thermometer used had its bulb covered with silver foil, and direct radiation from the fire was prevented by the interposition of a sheet of aluminium foil 3 inches square, which was fixed 4 inches from the thermometer bulb. The foil did not prevent radiation from the walls and other objects warmed by the fire, but it is probable that the effect of such radiation was very small. This is suggested by the temperatures of two 6-inch globe thermometers and a protected silvered thermometer which are recorded in Figure 2. The thermometers were fixed 6 feet from the gas fire, and it will be seen that during the first hour and a half, when they were in still air, the temperature of the copper globe thermometer rose 0.8° higher than that of the glass globe thermometer. During the next hour and a half the fan was turned on, and the air movement caused a fall of about 6° in the globe thermometers, while the protected silvered thermometer, though it did not show an actual fall, had a retardation of 0.5° in its rate of rise of temperature. This retardation may have been due partly to a diminution in the radiation effect from the walls of the room.

TABLE 1.—EFFECTUAL RADIATION TEMPERATURE 6 FEET FROM FIRE

DIAMETER OF GLOBE	GLOBE MATERIAL	GLOBE COVERING	GAS FIRE				ANTHRACITE STOVE			
			Still Air Temperature		Moving Air Temperature		Still Air Temperature		Moving Air Temperature	
			Globe Cloth Covered	Globe Painted Black	Globe Cloth Covered	Globe Painted Black	Globe Cloth Covered	Globe Painted Black	Globe Cloth Covered	Globe Painted Black
in.			°F.	°F.	*% of still air temperature*		°F.	°F.	*% of still air temperature*	
9	pasteboard	dark cloth or black paint	12.3	11.5	54	44	4.9	5.0	39	37
6	"	same	12.1	11.1	51 (49)	42 (43)	4.6	4.7	40 (36)	34 (34)
2.5	glass	"	11.3	10.3	47	45	4.3	4.2	30	31
0.3	"	"	7.9	6.1	46	41	3.4	3.0	34	34
6	pasteboard	white linen	10.4	...	49	..	4.7	..	39	..
6	glass	black paint	...	12.3	..	44	..	5.0	..	32
6	copper	" "	...	12.5	..	45	..	..	..	..

Meteorologists endeavor to exclude radiation effects by placing their thermometers in a Stevenson screen; therefore series of observations were made with a standard screen. As they gave distinctly less favorable results than the silvered thermometer protected from direct radiation by aluminium foil, the readings of this thermometer were assumed to indicate the true air temperature.

The mean effectual radiation temperatures observed when the thermometers were fixed 6 feet from the gas fire are shown in Table 1. Of the four thermometers covered with gray cloth, the 9-inch globe thermometer showed a slightly higher temperature than the 6-inch thermometer. The $2\frac{1}{2}$-inch thermometer (a solar radiation thermometer covered with cloth) showed a slightly lower temperature than the larger globes, while an ordinary small-bulbed thermometer, covered with a finger stall of cloth, showed a considerably lower temperature. When globes of the various sizes mentioned were covered with mat black paint instead of gray cloth, they showed a slightly lower radiation temperature in each case. Also they responded more to moving air than did the cloth covered thermometers, for it will be seen from the table that their effectual radiation temperature was reduced to 43 per cent. of its still air value, as compared with a reduction to 49 per cent. in the cloth covered thermometers.

The data recorded in the lower part of Table 1 indicate that a globe covered with white linen had a slightly lower effectual radiation temperature than the gray cloth globe.

Radiation from Stove

Most of the observations on gas fire radiation were repeated on stove radiation. The anthracite stove employed was 29 by 22 inches in area, and it stood in a shuttered and curtained room 18 by $15\frac{1}{2}$ feet in area, or the same size as the gas fire room. The surface of the stove probably had a temperature of about 350°F., for all high temperature radiation from it was prevented by placing a metal plate behind the mica door. The thermometers were fixed 6 feet from the stove and 3 feet above the floor. It will be seen from Table 1 that the effectual radiation temperature was not half so great as from the gas fire, but that it showed a roughly proportional reduction as the size of the globes diminished. The painted globes, however, showed as high a radiation temperature as the cloth covered globes, and nearly the same reduction of temperature in moving air (270 feet per minute). This reduction was distinctly greater than in the gas fire observations, for the mean moving air temperature was only 35 per cent. of the still air temperature instead of 46 per cent.

Globe Thermometer Temperature in Relation to Sensations of Warmth

The globe thermometer indicates the effectual radiation temperature over and above the convection air temperature. Hence the globe thermometer itself indicates the combined effects of radiation and convection. Its practical value depends on its accuracy as an index of the warmth sensations created in the human body by any and every combination of radiant heating and convection heating experienced, not only in rooms heated in various ways, but out of doors in the presence and absence of solar radiation. Before proceeding to describe the evidence obtained in support of the reliability of the instrument, it is necessary to adduce some control experiments indicating the relationship between the globe

thermometer temperature and the globe surface temperature.

A 6-inch, gray cloth covered globe was used throughout the experiments. This globe was fixed to the top of a telescopic rod, which was rotated by a clockwork motor at the rate of two revolutions a minute (see Fig. 3). A thermometer (not shown in the figure) was inserted with its bulb in the middle

FIG. 3.—Showing cloth covered globe on revolving rod.

of the globe. The surface temperature of the globe was ascertained by means of a Moll thermopile (5, p. 2). The mouth of the cone of the thermopile is 2.36 inches (6 cm.) in diameter, and it was held close to the rotating globe in four positions successively, one edge being at the upper or the lower pole of the globe or at the equator. There was a very slight overlapping of the areas covered by the cone, but it was calculated that the area covered when the edge of the cone was against the equator was approximately double the area covered when it was against a pole. The temperature readings calculated from the readings of the galvanometer connected with the thermopile were therefore weighted in the same proportion, in order to get the average temperature of the whole globe surface.

When the globe was taken from a cold room to one 20° warmer, its surface temperature warmed up rather more rapidly than the contained thermometer, and five sets of observations showed the following average lag of the thermometer on the surface:

Time	*Globe Transferred from Cold to Warm Room*	*Gas Fire Lighted in Cold Room*
hrs.	*°F.*	*°F.*
½	1.2	1.3
1	0.5	0.9
1½	0.3	0.0
2	0.1	0.0

Observations made when the gas fire was lighted in a cold room showed about the same amount of lag, as can be seen from the data adduced.

The method of revolving the globe slowly insures an even heating on all sides, and enables one to ascertain the average temperature of the whole surface with a minimum of trouble. A stationary globe, however, was found to give almost the same result when it was tested on the exposed side and on the other three sides 90° or 180° from it, and an average taken.

The observations on radiation-convection temperatures in relation to sensations of warmth were made on two subjects, Mr. C. G. Warner and

myself, and we always endeavored to arrange that the atmospheric conditions should be such as to induce a pleasant sensation of comfort. We recorded our sensations every fifteen minutes in accordance with the following scale, which we used in our previous observations:

Much too warm	= 1
Too warm	= 2
Comfortable	= 3
Too cold	= 4
Much too cold	= 5

In no instance did the average atmospheric conditions experienced during the experimental hour induce in either of us a sensation ranging beyond the limits of 2.8 and 3.2 units, and as we reacted almost alike, the sensation values are quoted in the last column of Table 2 as averages. It will be seen that these averages range only from 2.9 to 3.1; therefore we may consider that all the observations were made under atmospheric conditions inducing comfortable warmth.

In the gas fire observations the air temperature of the room varied from 48° to 58.1°, and we had to sit from 5 to 10 feet from the fire in order to obtain sufficient radiant heat to create a comfortable sensation of warmth. We sat opposite each other, and shoulderwise to the fire. The distance was measured from the center of the fire to the exposed shoulder of each subject, and to the equator of the cloth covered globe, not to its center. The globe and the protected ordinary thermometer were opposite the center of the fire and 8 inches apart, while we sat with our bodies 15 inches from the globe or the thermometer, in the arc of a circle with the fire at its center. Although we were the same radial

TABLE 2.—RADIATION-CONVECTION TEMPERATURES INDUCING COMFORTABLE WARMTH

SOURCE OF RADIANT HEAT	MEAN DISTANCE FROM SOURCE	NO. OF HOURLY OBSERVATIONS	MEAN AIR TEMPERATURE	CORRECTED EFFECTUAL RADIATION TEMPERATURE	RADIATION-CONVECTION TEMPERATURE EXPERIENCED BY SUBJECTS	MEAN SURFACE TEMPERATURE OF CLOTHING	MEAN SENSATION OF WARMTH
	ft.		°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Gas fire	5.8	6	49.3	12.8	49.3+12.8 = 62.1	70.8	3.1
	6.8	4	53.8	7.7	53.8+ 7.7 = 61.5	71.4	3.0
	9.1	5	57.2	4.6	57.2+ 4.6 = 61.8	72.4	3.0
Stove	6.0	3	56.5	6.3	56.5+ 6.3 = 62.8	73.0	3.0
	6.0	3	59.0	2.4	59.0+ 2.4 = 61.4	72.9	3.0
	6.8[1]	5	61.2	0.4	61.2+ 0.4 = 61.6	73.4	3.0
Ceiling panels	9.0	4	60.8	1.6	60.8+ 1.6 = 62.4	73.3	2.9
	15.0	4	61.7	1.2	61.7+ 1.2 = 62.9	73.6	3.0

[1] Stove screened.

distance from the fire as was the globe surface, we received slightly less radiation, in accordance with the cosine law. The reduction of radiation ranged only from 6 per cent. to 2 per cent., however, and a correction has been made for it in the effectual radiation temperatures recorded in Table 2.

In order to equalize the radiant heat received by the two sides of the body, the subjects—who were clad in dark clothing—changed places every seven and one-half minutes. The fifteen observations—each of an hour's duration—made in the gas fire room have been split into three groups and averaged, and it will be seen from Table 2 that at a mean air temperature of 49.3° the effectual radiation temperature amounted to 12.8°, making the combined radiation-convection temperature experienced by the subjects 62.1°. At mean air temperatures of 53.8° and 57.2° the effectual radiation temperatures amounted to 7.7° and 4.6°, respectively, and the radiation-convection temperature came to 61.5° and 61.8°. It appears, therefore, that the globe temperature affords a good index of comfort, even when the relative proportions of radiant heat and of convected heat on which it is based vary considerably.

The observations on stove radiation support those on gas fire radiation. The effectual radiation temperature of the stove was not half so great as that of the gas fire; for this reason the air temperature had to be correspondingly raised, but the combined radiation-convection temperature came to 62.8° and 61.4° in the two groups of observations made. A third set of observations was made with a wooden screen interposed between the stove and the subjects. This converted the heating into a convection system, for the effectual radiation temperature amounted only to 0.4°; yet the radiation-convection temperature was 61.6°, or almost the same as in the other series.

The observations on ceiling panel heating were made in a room 33 by 19 feet in area, and 12 feet, 4 inches in height. It was warmed by four ceiling panels on the window side of the room, each 8 by 6 feet in area, and with a surface temperature of about 95°. When we sat directly under a panel, or about 9 feet from its surface, the cloth covered globe indicated an effectual radiation temperature of 1.6°, and when we sat at an average distance of 15 feet from the panels this temperature fell to 1.2°. The combined radiation-convection temperature came to 62.4° in the first position and to 62.9° in the second. This is slightly higher than in the gas fire and the stove rooms, the difference being due to the greater air velocity in the ceiling panel room. Kata-thermometer observations showed that the air velocity averaged 20 feet per minute as compared with 12 feet per minute in the other rooms.

The consistency of the individual observations which are averaged in Table 2 can be gathered from the fact that their average difference from the mean temperature of 62° amounted only to 0.7°.

Directly after the two subjects changed from side to side, one or the other of them measured his body surface temperature by means of the thermopile. The instrument was held close to the surface of the clothing in

the following seven positions: (1) and (2) on the shoulders midway between the neck and the insertion of the arm; (3) and (4) the outer sides of the two arms at a height of 3 feet above floor level; (5) the front of the chest at the same height; (6) and (7) near the middle of each thigh on its outer to under side (with the thermopile held at an angle of 45° to the floor). The observed temperatures were averaged, but in order to render the average more comparable to that of the globe surface, where the polar readings were weighted only half as much as the equatorial readings, the two shoulder readings were combined before they were averaged with the rest. The mean clothing temperatures of the two subjects, recorded in Table 2, average about 73°. This is 2° lower than the value of 75° quoted by Dufton, but as his subjects considered a "comfortably warm" air temperature to be 64.3°, while we ourselves considered it to be 62°, it follows that our mean surface temperature figure corresponds closely with his. As we felt comfortably warm in all the observations, it might be thought that our clothing temperatures would be nearly constant; yet we see that in the observations made in the gas fire room at an air temperature of 49.3°, the clothing was 2.6° cooler than in those made in convected air at a temperature of 61.2°. Probably this discrepancy was due to our getting up and changing places just before we measured our surface temperatures. The fairly rapid movement entailed must have cooled our body surface more when the air was cool than when it was warm. The reason why places were changed just before the measurements were made was in order to get some sort of equality between the surface temperatures of the two sides of the body, one of which was rapidly warming, and the other rapidly cooling.

It may be questioned whether the surface temperature of the globe, which was 3 feet above floor level, was a fair index of the radiation received by the bodies of the seated subjects. In order to test the point, a series of observations was made with the Moll thermopile (with its glass disk inserted). These showed that the radiation 6 feet from the fire at a height of 3 feet was 98 per cent. of the average of that received at all levels of the seated subject.

Radiation and Convection in Various Heating Systems

In Table 1 it is recorded that when the 6-inch cloth covered globe thermometer was at a distance of 6 feet from the gas fire tested, it indicated an effectual radiation temperature of 12.1°, while it indicated only 4.6° —or about a third as much—when at the same distance from the anthracite stove. We see from Table 2 that ceiling panels induced only a third as great a radiation temperature as did the stove; thus it follows that these three systems of heating differ very greatly in their capacity for radiation. This is already well known, but hitherto no numerical estimate of the differences has been put on record. Also it is known that the strength of the radiation impinging on various parts of the human body differs considerably, and the differences in surface temperature of various portions of the cloth covered globe afford an indi-

cation of these variations. Averages of the surface temperature of the four globe areas tested are plotted in Figure 4, and it will be seen that at a distance of 5.8 feet from the gas fire, the top segment of the globe had an effectual radiation temperature of only 7.1°, while the bottom segment had a temperature of 14.8°, the intermediate segments having intermediate

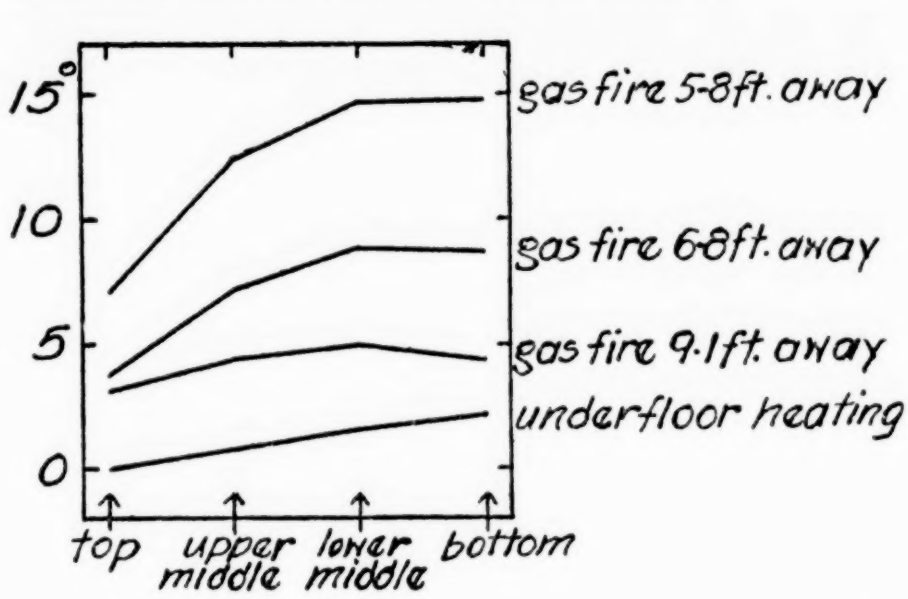

FIG. 4.—Surface temperature of cloth covered globe in excess of air temperature.

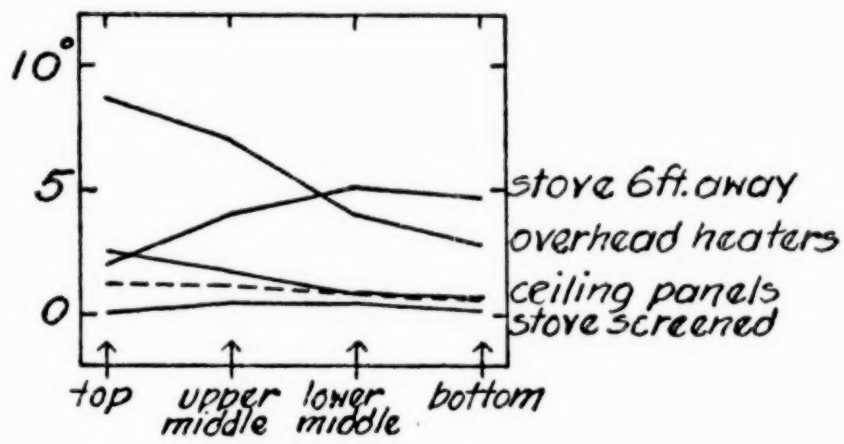

FIG. 5.—Surface temperature of cloth covered globe in excess of air temperature.

temperatures. When the globe was 9.1 feet from the fire its surface was naturally of a more equable temperature, the extremes varying from 3.1° to 5°.

The radiation from the stove caused greater variations than that from the gas fire, for the mean of all the observations made at 6 feet from the fire gave excess radiation temperatures of 2.1° at the top segment and 5.1° at the lower middle one, as can be seen from Figure 5. When the stove was screened, the middle segments of the globe showed a radiation temperature of 0.5°.

When the source of radiant heat is in the ceiling, the top segment of the globe naturally shows the highest temperature. It will be seen from Figure 5 that when the globe was directly under a ceiling panel, which was 9 feet above it, the top segment had an excess temperature of 2.6°, and the bottom one, an excess of 0.8°. When the globe was placed 15 feet from the panels the surface temperatures ranged only from 1.3° to 0.7°; thus it follows that the radiation from ceiling panels at a temperature of about 95° is

of so mild a character that the radiation striking the head of any person sitting below would scarcely be appreciable. This statement may appear to be a truism in the light of these globe observations, but the possibility that the head would be heated unduly by the radiation from ceiling panels has been suggested to me by a number of critics of the panel system.

When the temperature of the ceiling panels is raised considerably, the radiation on the head may become unpleasant. A new system of heating by means of small heating elements of high temperature has recently been introduced (6) (7). These elements are composed of ceramic material, and are usually 2 feet by 1 foot in area. On the under side is imbedded a zigzag ribbon of graphite through which an electric current is sent. This heats the surface to as much as 500°F., and as the intensity of the radiation varies inversely as the fourth power of the absolute temperature (Stefan's law), it follows that at an air temperature of 60° the effectual radiation received from one of these panels is thirty times greater than that from a panel of equal size at a temperature of 100°. Observations were made in a schoolroom, 30 feet by 13 feet in area, which was warmed by six of these heating elements. The elements were suspended 10 feet above the floor, and when the 6-inch cloth covered globe was placed 3 feet above floor level, at a spot midway between three heating elements, it was found to attain a mean excess surface temperature of 8.7° in the upper polar region, and of 2.9° in the lower polar region (see the curve plotted in Figure 5). The teacher, who usually stood at one end of the classroom, was often directly under a heating element, and a cloth surface fixed horizontally where the top of his head came soon took up a temperature 19° above that of the air. Therefore these very hot heating elements ought to be fixed as high above the floor as possible, so as to effect more equalization of the radiation. If they were placed close to the ceiling, there would be a considerable saving of heat wasted in warming the upper strata of air. Thus the air 12 feet above the floor of the classroom, or 2 feet above the heating elements, was found to be 13.5° warmer than at floor level.

When the heating source is on the floor instead of in the ceiling or at the sides of the room, the lowest segment of the cloth globe is naturally the warmest. Observations made in a schoolroom in which the whole of the floor surface was warmed to 69° by means of underfloor hot water pipes (8), are plotted in Figure 4, and it will be seen that the lowest segment of the globe had a surface temperature 2.2° above that of the air. The lower middle segment had an excess of 1.6°, the upper middle segment one of 0.8°, while the top segment had the same temperature as the air. The mean effectual radiation temperature of the globe surface was 1.2°, and, as the mean effectual radiation temperature observed in the low temperature ceiling panel observations previously described averaged 1.4°, it follows that the underfloor system heats about as much by radiation as does the low temperature ceiling panel system. This is considerably less than the high temperature

heating elements, which were found to create an effectual radiation temperature of 5.7°.

Effects of Changes in Convection Air Heating on Globe Thermometer Readings

Methods of heating such as the plenum air system, which are based almost entirely on convection air heating, might be thought to cause very little variation in the effectual radiation temperature indicated by the globe thermometer. This is by no means the case, and the observations to be described show in striking fashion how inaccurate a picture air temperatures of plenum air heated rooms may yield, if considered apart from effectual radiation temperatures.

The first set of observations to be described was made in a lecture theater, 53 by 46 feet in area. It is 12 feet high at the entrance, and with the fall of the rows of seats the height increases to 21 feet at the lecture table. It was heated by eight hot water pipe panels in the ceiling, each 8 by 6 feet in area, but as they maintained an air temperature of only about 55°, an auxiliary plenum air system was added. This blew in hot air through a series of gratings around the ceiling, while the air was extracted through other gratings under the seats. A fair amount of air movement was induced by this combined positive and negative ventilation, and the windows were usually kept shut.

When the 6-inch cloth globe was put 5 feet in front of the lecture table and 3 feet above floor level, its mean surface temperature was 1.1° above the air temperature. This was due to the radiation from the ceiling panels. When the hot plenum air was turned on, the temperature of the air—at a level of 3 feet—rose from 55.6° to 69.1° in the first hour, and subsequently to 71.4°, but the walls and floor of the room were so slow in warming up that after half an hour the cloth globe indicated an effectual radiation temperature no less than 4° below the air temperature. Even after four hours it was 2.4° below the air temperature, so that the effectual air temperature—*i.e.*, the radiation-convection temperature—instead of being 66.6° and 71.4° at the times indicated, was only 62.6° and 69°, respectively. It will be seen from Figure 6 that after four hours of plenum air heating the floor temperature, estimated by the plasticine method (5), was 8.1° lower than the air temperature at a level of 3 feet, while it was 2° higher than the air temperature when the panel system alone was functioning. The temperature of the air was measured at levels of 6 inches and $7\frac{1}{2}$ feet above floor level as well as at 3 feet, and it will be seen from Figure 6 that while there was a difference of only 1.5° between these levels when the panel system alone was working, it increased to 8.3° forty minutes after the plenum air was turned on.

It was customary to turn on the plenum air in the lecture room an hour or two before the lecture was held, and it is obvious that a simple statement that the air temperature in the room was, for example, 70°, would convey a very imperfect picture of the actual temperature conditions to which the persons attending the lecture were sub-

jected. Owing to negative radiation from the walls, the effectual temperature at head level would be 67° or less, instead of 70°, and the feet of the persons present would be resting on a floor at a temperature of 61°. No better proof could be desired than the curves in Figure 6 of the equableness of the temperature conditions created by panel heating, in contrast with the inequalities created by turning on the plenum system.

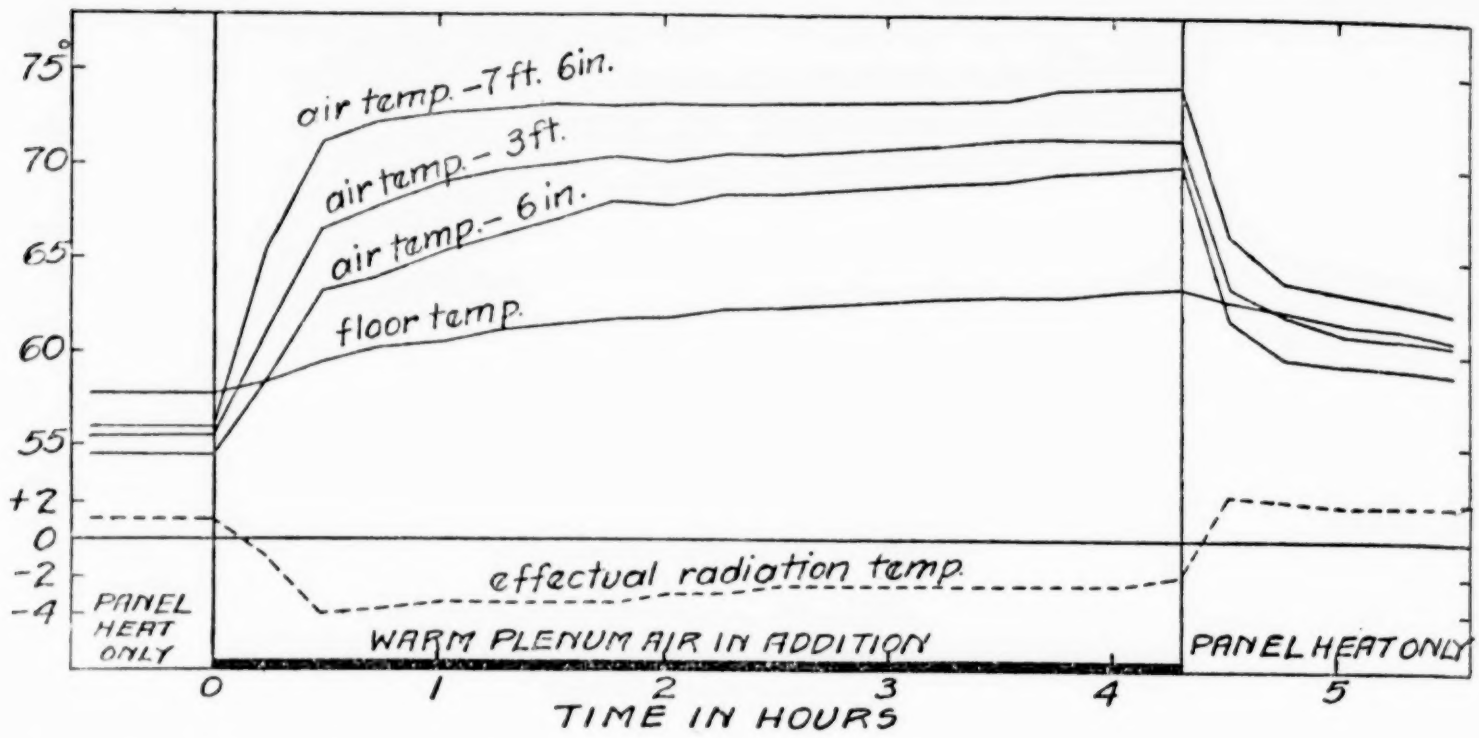

FIG. 6.—Effect of warm plenum air on temperatures in panel heated lecture room.

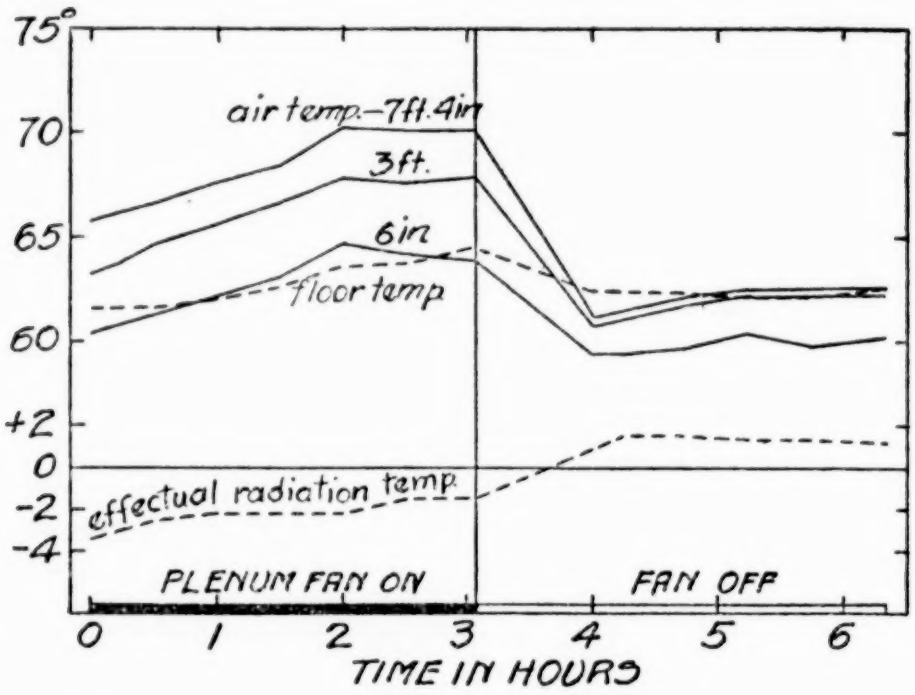

FIG. 7.—Effect of turning on and off warm plenum air in a factory.

It might be thought that in buildings such as factories the warm plenum air is turned on so long a time before the workpeople arrive that fairly equable conditions would be established. In my experience, the hot air is turned on about two hours before work begins, and in the few sets of observations made the inequalities were still considerable. Figure 7 shows a set of observations made in a room 120 by 54 feet in area, which was heated by

an overhead plenum system. The inlets of the pipes were 9 feet above the floor, and a series of 2-inch ducts discharged air horizontally at this level. Observations were made at a spot near the center of the room, the effectual radiation temperature being ascertained roughly by holding the Moll thermopile to the north, east, west, and south walls in turn, and to the ceiling and the floor. The first set of observations was made two and one-half hours after the plenum air had been turned on, and the mean temperature indicated was 3.4° less than the air temperature at the same level (5 feet above the floor). Three hours later it was 1.6° less, and then the hot air was shut off completely. In consequence the temperature of the room fell rapidly, and the temperature of the walls, etc., now became greater than that of the air, the mean effectual radiation temperature being 1.6° in excess. It will be seen from Figure 7 that an excess of over 1° was maintained for the next two hours.

The air temperatures at different levels did not vary so much as at the lecture theater, the floor temperature remaining fairly high throughout. Probably this was due to conduction of heat through the floor from the room below.

General Conclusions

Atmospheric conditions, when considered in relation to human comfort, depend on the degree of air movement as well as on the temperature. The dry kata cooling power of the air affords an index based on a combination of dry bulb temperature and air velocity, while the wet kata cooling power is a combination of wet bulb temperature and air velocity. Yaglou and his colleagues (9) have shown that both dry and wet bulb temperatures ought to be taken into account, and they have combined them with air velocity to form a single index termed "effective temperature." In the present observations on comfort in relation to radiation-convection temperature no mention was made of the wet bulb temperature because it was fairly steady; the relative humidity of the air in the various experiments ranged only from 55 to 71 per cent., the mean being 64 per cent. The extreme differences observed correspond to a difference of less than 0.5° on the effective temperature scale; thus, even if the wet bulb had been allowed for, the mean results would scarcely have been affected. At the same time, in order to obtain a really exact measure of the atmospheric conditions as they affect sensations of comfort, allowance should be made for the wet bulb temperature, as well as for the dry bulb temperature, the effectual radiation temperature, and the air velocity.

The kata-thermometer automatically makes a good deal of allowance for radiant heat effects, and it can be calculated from the data recorded in Table 1 that if the radiation from a given source caused a rise of, for example, 10° in a globe thermometer, it would cause a rise of 7.7° in a thermometer with a spherical bulb of the same volume as the bulb of the kata-thermometer (which averages 0.93 inch). This lack of adequate response to radiation can be allowed for by calculation. For instance, if a kata-thermometer, when protected from the direct radiation of a gas fire by a sheet of aluminium foil, showed a

cooling power of 7.8 at an air temperature of 55°, it can be calculated from the accepted formula that the air velocity was 20 feet per minute. If a globe thermometer indicated that the effectual radiation temperature was 10°, or in other words, that the radiation-convection temperature was 65°, it can be calculated that this temperature, at an air velocity of 20 feet per minute, corresponds to a cooling power of 6. This figure therefore represents the cooling power with due allowance for radiation.

The globe thermometer is likely to be useful for ascertaining the degree of radiation which gives the maximum amount of health and comfort. Undoubtedly a certain amount of radiant heat is more exhilarating than a dull uniformity of temperature such as is generally induced by hot water radiators and plenum air installations; in rooms warmed only by a gas fire, however, the inmates are apt to feel scorched on the side of the body exposed to the fire and too cold on the unexposed side. This is because the proportion of the heating due to radiation is too great, while that due to convection is too small. We have seen that ceiling panels heated to about 100°F. have an effectual radiation temperature of a little over 1°, but this is probably insufficient to yield the best combination of comfort and exhilaration. Small overhead heaters at a temperature of 500°F. were found to have a radiation temperature of about 6° when spaced 9 feet apart. This degree of radiation may prove more advantageous, but in an ordinary room with an ordinary degree of ventilation it would not be pleasant to have such powerful radiation in all parts of the room. The room would soon get much too hot, owing to the dissipation of heat from the surfaces radiated upon to the air in contact with them. The heaters would have to be fixed for the most part at one end or one side of the room, and not distributed all over it. Perhaps a system of panel heating inducing an effectual radiation temperature of 2° or 3° will be found to be best, if it is coupled with an increase in ventilation sufficient to keep the air at a reasonable temperature, and if there is some slight concentration of panels at one end or one side of the room.

The globe thermometer should prove to be useful to meteorologists for outdoor observations. Observations made during the summer months with copper, glass, and cloth covered globe thermometers gave closely corresponding results, the effectual radiation temperatures observed in the bright sun at midday being about 30°F. However, a globe thermometer covered with white linen showed a radiation temperature of only 10°.

Summary

The radiation received at a given spot from all directions can be summated and measured by means of the *globe thermometer*. In its most convenient form this consists of a 6-inch copper globe painted mat black. A thermometer with its bulb in the center of the globe indicates the combined effects of radiation and convection as they affect the human body, while the excess of the globe temperature over the air temperature indicates the *effectual radiation temperature*.

Thus, when the atmospheric conditions in rooms warmed by a gas fire, a stove, or ceiling panels were such as to create a sensation of comfortable warmth, the globe thermometer temperature was always about 62°F., although the air temperature varied from 49.3° to 61.7°, and the effectual radiation temperature from 12.8° to 0.4°.

At a distance of 6 feet from a gas fire and a stove the effectual radiation temperature was 12.3° and 4.9°, respectively. In a room with ceiling panels heated to 95°F. it was 1.4°, but with small overhead heating elements of high temperature it was 5.7°. An underfloor heating system gave an effectual radiation temperature of 1.2°.

The effectual radiation temperature is greatly influenced by the air velocity. An air current of 270 feet per minute lowered the effectual radiation temperature induced by a gas fire to less than half, and lowered that induced by a stove to a third, of the respective effectual radiation temperatures observed in still air.

The effectual radiation temperature of rooms in which hot plenum air is turned on and off may be as much as 4° below or above the air temperature, owing to radiation from the walls and other solid objects.

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BOOK REVIEW

THE PRACTICE OF SPECTRUM ANALYSIS WITH HILGER INSTRUMENTS, INCLUDING A NOTE ON THE VARIOUS TYPES OF EMISSION SPECTRA. By *F. Twyman*. Fifth edition. Paper. Pp. 53 and appendix. London: Adam Hilger, Ltd., 1931.

This very readable little book forms an interesting introduction to a subject that is of increasing importance to public health chemistry. A surprising amount of information is tucked away between its covers, ranging from the application of spectroscopy to biologic and mineralogic problems to those problems of the structure of matter which are solvable by investigations of live spectra at various temperatures.

The chapter headings are as follows: Types of Problem to Which Spectrographic Analysis Is Applicable; Spectrometers and Spectrographs; Books and Reference Tables; Ways and Means of Exciting Emission Spectra; Taking Spectrograms, Measuring Wavelengths and Identifying Elements; Quantitative Spectrum Analysis; The Various Types of Spectrum.

An appendix and bibliography corrected to Aug. 31, 1931, complete the book. A very clear description is given of the use of R. U. (raies ultimes) Powder recently developed by Ryde and Jenkins in determining the elements present in a given sample. The printing and illustrations are excellent.—*Lawrence T. Fairhall.*

J. I. H.
March, 1932